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A software tool for the automatic quantification of the left ventricle myocardium hyper-trabeculation degree

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Abstract

Isolated left ventricular non-compaction (LVNC) is a myocardial disorder characterised by prominent ventricular trabeculations and deep recesses extending from the LV cavity to the subendocardial surface of the LV. Up to now, there is no common and stable solution in the medical community for quantifying and valuing the non-compacted cardiomyopathy. A software tool for the automatic quantification of the exact hyper-trabeculation degree in the left ventricle myocardium is designed, developed and tested. This tool is based on medical experience, but the possibility of the human appreciation error has been eliminated. The input data for this software are the cardiac images of the patients obtained by means of magnetic resonance. The output results are the percentage quantification of the trabecular zone with respect to the compacted area. This output is compared with human processing performed by medical specialists. The software proves to be a valuable tool to help diagnosis, so saving valuable diagnosis time.

Keywords: non-compacted cardiomyopathy, trabecules, left ventricle, computing application, automatic quantification

1 Introduction

In the last fifteen years, non-compacted cardiomyopathy has aroused the interest of cardiologists as a consequence of the important technological development in the main cardiologic image techniques: echocardiography (EC), magnetic resonance (MR) and the multi-slice Computed Tomography (CT) [3]. Non-compacted cardiomyopathy is characterized by the presence of multiple trabecules in the left ventricle myocardium, associated to multiple inter-trabecular recesses communicated with the ventricular cavity [4][9]. Up to now, there is no stable agreed solution in the medical community for quantifying and valuing this cardiopathy.

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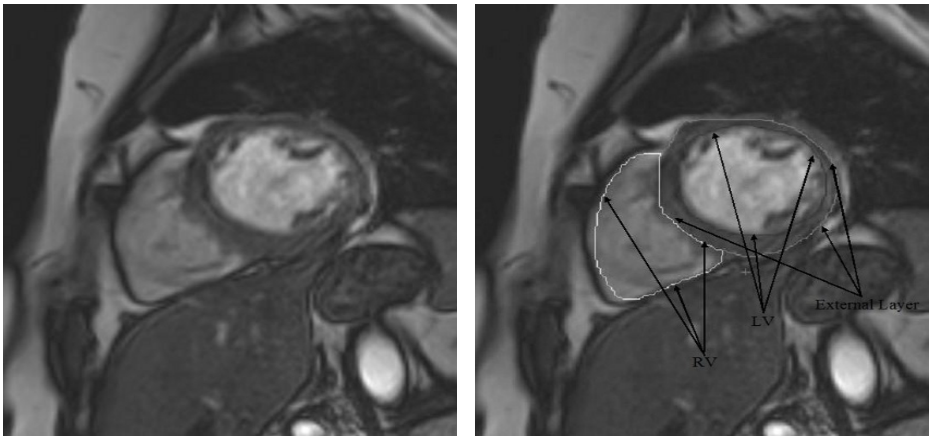
Currently, the detection of the non-compacted cardiomyopathy from an MR image of a patient, as presented in Figure 1a, in the Hospital Virgen de la Arrixaca at Murcia, Spain, is performed manually in order to detect the left ventricle cavity, including the trabecules (black zone in Figure 1b, identified as LV), the right ventricle cavity (white zone in Figure 1b, identified as RV) and the external layer (gray and white delimited zone in Figure 1b, identified as External Layer). The left ventricle layer appears divided in two zones: an internal one, where the trabecules are located, called trabecular zone (formed by several black zones inside the LV), and a dense external layer called compacted zone (all the area located between the external layer and the LV). In previous studies, the quotient of the thickness of the two zones has been specified as an established way for quantifying the trabecules [8] [13]. This quotient is calculated by the cardiologists for all the segments in each slice (the American Heart Association defines 17 segments to be studied [1]) and in all the slices of the LV from the apex (top) to the base (basal). The process is clearly influenced by the subjective and expert vision of the specialist, who needs to spend considerable time evaluating each image of a patient and often a large number of patients.



(a) (b)

Figure 1: (a) Original MR image of a patient. (b) Left ventricle cavity with trabecules (black delimited zone, identified as LV), right ventricle cavity (white delimited zone, identified as RV) and external layer (gray and white line, identified as External Layer).

Jacquier et al. [7] describe a pioneer work to computationally quantify the trabeculated mass by endocardium delineation. However, the proposed method was applied to a very small number of patients and the classification shown is based on the variables defined previously by the same method.

In this work, based on our experience in the application of 3D wavelet transform for high-quality compression of medical video [2][5], we propose an approach which applies a series of computational techniques[1] to Quantify the LV hyper-Trabeculation (QLVT) degree, using the cardiac images obtained by magnetic resonance (Figure 1b). The developed software tool is based on medical experience, but the possibility of the human appreciation error is eliminated. The output results are the percentage quantification of the trabecular zone with respect to the compacted one. The computational method can save valuable diagnosis time when compared with the human processing.

[1]Based on the ltmser algorithm [11] for the detection of stable regions implemented in QVision, a computing vision library for QT [12].

The rest of the paper is organized as follows. Section 2 outlines the implementation of the computing method proposed. Several experiments to test the proposal are presented in section 3. Finally, section 4 summarizes the work, concludes the paper and introduces future work.

2 The computing method: QLVT

A cardiac image of magnetic resonance is composed of a determined grid of pixels in gray scale, as presented in Figure 1a. QLVT has to identify the left ventricle cavity among different structures, like the stomach, the liver, the right ventricle myocardium, etc. Also, it is necessary to identify the right ventricle cavity to delimit the external layer of the LV, formed by the external layer of the myocardium and the right part of the external layer of the RV cavity. All structures represent similar geometric figures composed of a mass of pixels in a gray scale range. The LV cavity is normally represented by a set of pixels near to white making a circular figure. The RV cavity is located in the magnetic resonance on the left of the LV cavity, and consists of a large group of pixels in a determined range of gray values. The external layer of the myocardium is characterized by a thin black zone. The method applies a series of computational techniques based on the ltmser algorithm [11] to detect different structures (stable regions), implemented in QVision[2] [12], in the cardiac images of a person obtained by magnetic resonance. The tool automatically selects the left ventricle cavity and the right ventricle cavity among the different stable regions detected previously, and searches the black zone of the external layer of the myocardium in order to establish the external layer of the LV. Another essential target is the detection of trabecular zones, which are characterized by grayish or black zones in the interior of the LV. These trabecular zones are composed of a set of closed pixels, making small clouds, with values near to black or in a gray range lower than the rest of the pixels of the LV cavity. The method detects the different clouds (stable regions) by applying the ltmser algorithm to the LV cavity, and quantifies the trabecular zones. The compacted zone is the area located between the LV cavity and its external layer. The output result is the percentage of the trabecular zone with respect to the compacted area for each cardiac image.

Algorithm 1 shows a general method for detecting the LV cavity, the trabecular zone and the compacted zone in a cardiac image obtained by magnetic resonance. The algorithm obtains the areas of the trabecular zone and the compacted zone in order to compute the percentage quantification of the trabecular zone with respect to the compacted area.

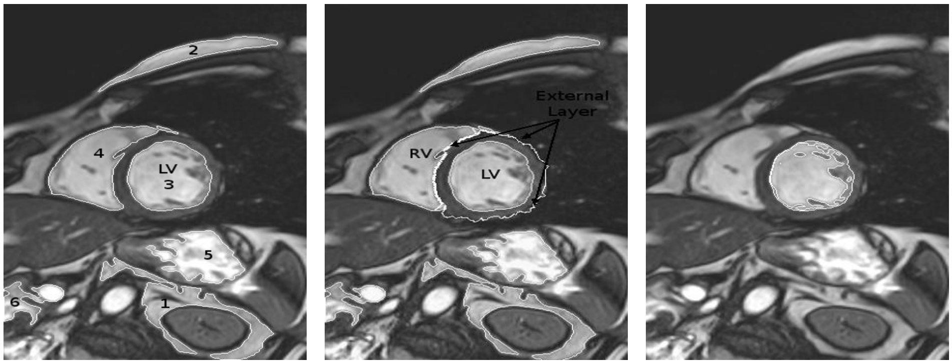
Algorithm 1 General method for detecting and computing the areas of the trabecular zone and the compacted zone in the LV. It obtains the percentage quantification of the trabecular zone with respect to the compacted area

1: Detect different MSERs and identify LV cavity
2: Identify RV cavity and detect external layer of compacted zone
3: Detect different trabecular zones
4: Compute areas of trabecular zones and the compacted zone in the LV
5: Obtain percentage quantification of the trabecular zone with respect to the compacted area

In step 1, the input of QLVT is a cardiac image obtained by magnetic resonance. Ltmser [11] detects the different Maximally Stable Extremal Regions (MSER). Each MSER is a stable mass of pixels in a determined gray scale range, has an irregular shape, and contains the coordinates of the vertices in an image. As the LV cavity is normally represented by a circular shape, the

[2] A computing vision library for QT (a cross-platform application framework that is widely used for developing application software that can be run on various software and hardware platforms with little or no change in the codebase, while having the power and speed of native applications).

centroid of each MSER detected is computed in order to identify automatically the left ventricle cavity. The area of the LV cavity is computed. In Figure 2a, we observe the different MSERs, numbered from 1 to 6, detected (all vertices in white) for a cardiac image and the identification of LV cavity.

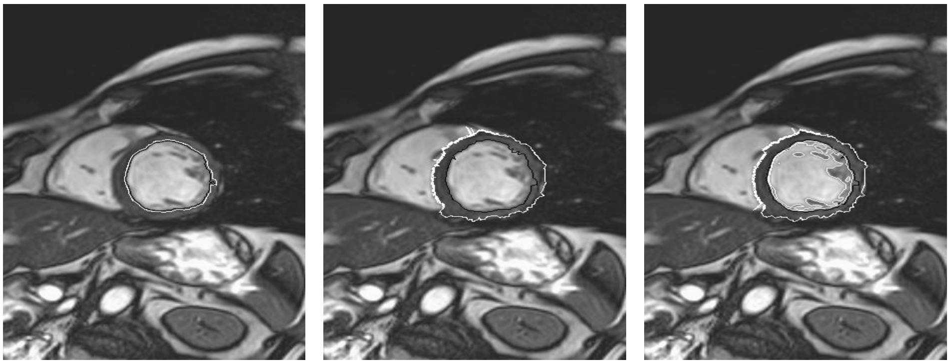


(a) (b) (c)

Figure 2: (a) Different MSERs (numbered from 1 to 6) detected for a cardiac image, and the identification of LV cavity. (b) RV cavity identified on the left of the LV cavity, and external layer of the compacted zone (in white). (c) Several contours detected inside the LV cavity.

In step 2, from the LV cavity detected as the reference point, the method automatically finds the right ventricle cavity among the different stable regions, detected in step 1. In an image, the RV cavity is located on the left of the LV cavity. As QLVT distinguishes the different MSERs and their centroids, a search based on Bresenham algorithm [10] is implemented to draw straight lines between the centroid of the LV cavity and the other centroids of the MSERs detected in order to identify the RV cavity. The external layer of the myocardium is characterized by a thin black zone. QLVT searches this zone formed by different value pixels close to zero to delimit the compacted zone between the right part of the external layer of the RV cavity and the external layer of the myocardium. It is possible to adjust the external layer depending on the intensity of the black zone. In Figure 2b, the RV cavity, the LV cavity and the external layer of the compacted zone (in white) can be observed. QLVT computes the total area delimited by the external layer of the compacted zone.

In step 3, a multiple searching process of trabecular zones is made because these areas could be found in the interior or around the letf ventricle cavity. The trabecular zones are characterized by a closed range of gray-scale value pixels lower than the rest of the pixels belonging to the LV cavity. The ltmser algorithm is applied in the interior of the LV cavity to obtain the borders of connected and closed sets of pixels (contours or clouds), containing gray-scale values equal or greater than a given threshold. The threshold is determined by experienced medical specialists and the contrast of the input image. In Figure 2c, several contours are detected into the LV cavity (in white). These contours are the trabecular zones inside the LV cavity. The area of each contour is computed. For some patients, some trabecular zones are found around the LV cavity, and those zones are identified by a search based on the Bresenham algorithm, as we observe in Figure 3a, where the LV wall (in black) and a trabecular zone (in grey) around the LV cavity are established. QLVT finds and computes the area of these possible trabecular zones. Furthermore, a complementary search step, again based on the Bresenham algorithm, from the external layer of the compacted zone to the trabecular zone around the LV cavity is implemented to completely delimit the external layer of the trabecular zone. In Figure 3b, the external layer of the compacted zone (in white) is maintained with respect to the previous step (shown in Figure 2b). However, the external layer of the trabecular zone (in black) is modified with respect to the previous external layer detected in the trabecular zone (shown in Figure 3a in white). QLVT computes the area occupied by the trabecular zone.



(a) (b) (c)

Figure 3: (a) LV cavity (in black) and trabecular zone (in white) around the LV cavity. (b) External layer of the trabecular zone (in black) around the LV cavity and the external layer of the compacted zone (in white). (c) The LV cavity (in white), the trabecular contours inside the LV cavity (in white), the extenal layer of the trabecular zone (in black) and the external layer of the compacted zone (in white).

Finally, in step 4, QLVT obtains the total areas occupied by the LV cavity, the trabecular contours in the interior of the LV cavity, the trabecular zone around the LV cavity and the compacted zone. All these zones are identified (LV cavity, the trabecular contours inside the LV cavity and the external layer of the compated zone are in white, whereas the external layer of the trabecular zone is in black) in Figure 3c. The area of the compacted zone is the total area determined by the external layer of the compacted zone minus the total area delimited by the external layer of the trabecular zone. In the same way, the area of the trabecular zone is the total area determined by the trabecular contour minus the area of the LV cavity plus the areas of different trabecular contours detected in the interior of the LV cavity. The percentage quantification of the trabecular zone is the area of the trabecular zone divided by the sum of the areas of the compacted zone and the trabecular zone (step 5).

The output of the algorithm allows cardiologists to quantify the exact trabeculation degree in the LV quickly and automatically.

3 Results

We have applied the computing method presented in section 2 to 122 cardiac images obtained by magnetic resonance in a population of 18 patients (identified from P1 to P18) with non-compacted cardiomyopathy previously diagnosed and to two control groups of 9 patients in each: the first group is formed by people with magnetic resonance studies due to other cardiomyopathies, and the second group by people with magnetic resonance studies thanks to familiar screening who has been diagnosed as healthy, and so genetically prove negativity. Some patients received intravenous contrast before the magnetic resonance images acquisition.

The magnetic resonance studies were performed with a 1.5 T scanner (Achieva VC, Philips Medical Systems, Best, Netherlands) between 2004 and 2012. The images were obtained in synchronisation with the ECG and in apnea. The left ventricle function was evaluated with a free precision in standard stable balance (repetition interval of 2.8 ms., echo time of 1.4 ms., flip of 60, matrix of 190×200, echo train length of 23, cutting thickness of 8 mm, with

30 phases). The post-processing to determine the ventricular parameters was performed with an independent workstation provided by the manufacturer (View-Forum 6.3, Philip Medical System).

3.1 Quality evaluation by cardiologists

To assess the performance of the proposed method, a subjective evaluation on the output images with the identified zones was performed by two skilled cardiologists. The images were graded by specialists, using the scale proposed in [6] (Table 1).

Table 1: Evaluation scale to measure the diagnostic quality of medical images

5.0	Exact match: there is no noticeable differences
4.5	
4.0	Noticeable differences: they are not diagnostically significant
3.5	
3.0	Small diagnostically significant differences
2.5	
2.0	Significant diagnostic information is lost
1.5	
1.0	Large diagnostically significant differences

The evaluation results shown in Table 2 were obtained from the cardiologists when the computing method proposed outputs the different images of a patient with the LV cavity, trabecular zones and compacted zone identified. For each image of a patient, cardiologists observe the original image and the output of the proposed method. Based on the results reported in Table 2, it is understood that the visibility is clear in all cases. For all the experimented sequences, the cardiologists would be able to detect the presence of diagnostic features clearly, and an exact measure of the areas of LV cavity, compacted zone and trabecular zone can be obtained in a short time. 100% of the evaluated images have no noticeable differences for diagnosis. Moreover, most of the tested images are exact and have not one different pixel from what an expert cardiologist could determine.

Table 2: Results of average quality measure obtained from cardiologists for images with LV cavity, trabecular zones and compacted zone identified

	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Cardiologist 1	56.56%	40.98%	2.46%	0%	0%	0%	0%	0%	0%
Cardiologist 2	46.34%	36.59%	14.63%	2.44%	0%	0%	0%	0%	0%
Average	53.70%	40.12%	5.56%	0.62%	0%	0%	0%	0%	0%

3.2 Detailed evaluations

We analyze different types of images to confirm QLVT is capable of detecting and measuring the LV cavity, the trabecular zones and the compacted area in different situations. The software offers the opportunity of adjusting a threshold to detect the trabecular zones and the intensity of the black zone to determine the external layer of the compacted zone.

In Figure 4, the area of compacted zone (ACZ) and the area of trabecular zone (ATZ) for differents slices, from the apical to the basal, of the patients in the two control groups are presented. There are great differences among the values of the areas, for all the patients and slices, showing QLVT is capable of detecting LV cavities of several sizes. For a particular patient, the general trend is to obtain higher values of trabecular zones than the compacted zone in the apical slices up to the central ones and to reduce the importance of the trabeculated areas in the basal slices. For example, several slices of the patients P1, P3, P5 and P7 obtain important areas for the compacted zones and trabecular zones, with values higher than 8000 and 4000 pixels, respectively. Therefore, the percentage quantification of the trabecular zone, as

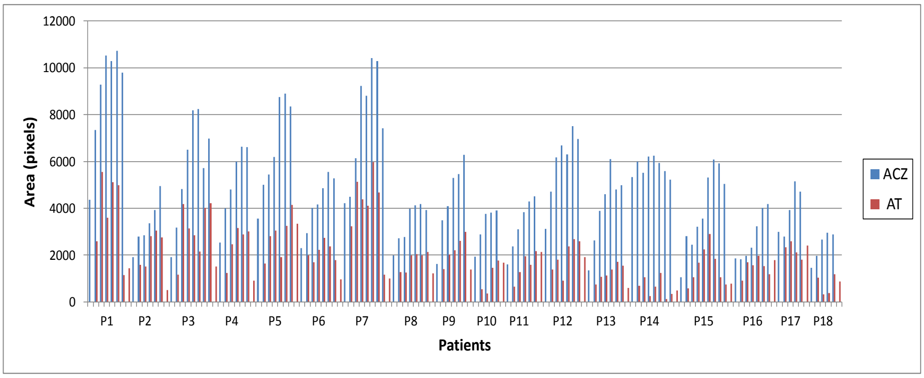


Figure 4: Area of compacted zone (ACZ) and of trabecular zone (ATZ) computed by QLVT for different slices of patients.

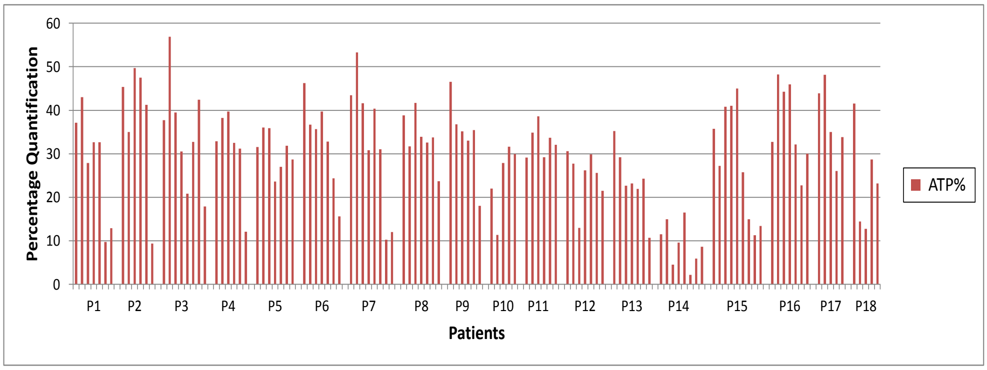


Figure 5: Percentage quantification of the trabecular zone (ATP%) computed by QLVT for different slices of patients P1, P2, ..., P18

we can observe in Figure 5, reaches the highest values of 43.00%, 56.89%, 36.01% and 53.31% in the slices 2 of P1, P3, P5 and P7, and the lowest values of 9.72% in the slice 6 of P1, 17.87% in the slice 8 of P3, 23.65% in the slice 4 of P5 and 10.22% in the slice 7 of P7. On the other hand, patients P8, P10, P16 and P18 present narrow compacted zones and trabecular zones lower than 4000 and 2000 pixels. Now, the percentage quantification of the trabecular zone ranges from 23.72% to 41.69% in P8, 11.36% to 31.66% in P10, 22.75% to 48.20% in P16 and 12.72% to 41.51% in P18. All mentioned slices with the LV cavity, trabecular zones and compacted zone identified have been evaluated by cardiologists with 5.0 or 4.5, showing that QLVT precisely detects and accurately measures both insignificant and very important trabecular zones.

In all patients, it is possible to configure the intensity of the black zone to determine the external layer of the compacted zone by the cardiologists to obtain wide or narrow compacted zones. Figure 6 shows the output of QLVT (LV cavity, trabecular zone and compacted area) for slices 3 of P1, 7 of P7 and 5 of P18. The areas of compacted zone of P1 and P7 are wide and achieve values of 9278 and 10291 pixels, whereas the trabecular area is 3592 and 1171 pixels. Thus, the percentage quantification of the trabeculated zone are 27.91% and 10.22%. However, P8 presents a narrow compacted zone with an area of 2878 pixels and a trabecular zone of 867 pixels. Hence, the percentage quantification of the trabecular zone is 23.15%. All these slices have been evaluated by cardiologists with a 5.0, so demonstrating QLVT is able to detect wide or narrow compacted zones accurately.

Patients P2, P3, P4, P6, P7, P10, P11, P16 and P17 received intravenous contrast before

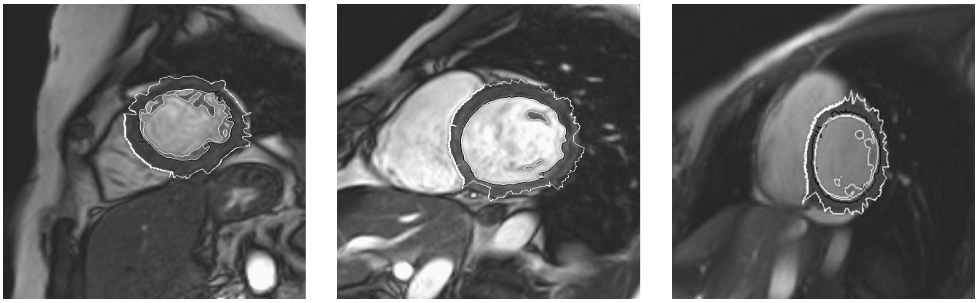


Figure 6: Outputs with LV cavity, trabecular zone and compacted zone identified, for slices 3, 7 and 5 of patients P1, P7 and P18

the magnetic resonance. Therefore, the threshold to detect the trabecular zones, which has been easily configured and adjusted by cardiologists, is higher than in the other cases because the pixels which make the LV cavity have higher intensity. For example, Figure 7 presents the outputs of QLVT for slice 4 of patients P2, P3 and P6, with identification of LV cavity, trabecular zone and compacted area. The percentage quantification of the trabecular zone is 49.70%, 30.50% and 39.70% for P2, P3 and P6. As we can observe, in three images there is a higher intensity in the different stable regions due to the contrast received by patients. However, the LV cavity and the trabecular and compacted zones are well delimited because the cardiologists scored these zone delimitations with 5.0, 4.5 and 5.0.

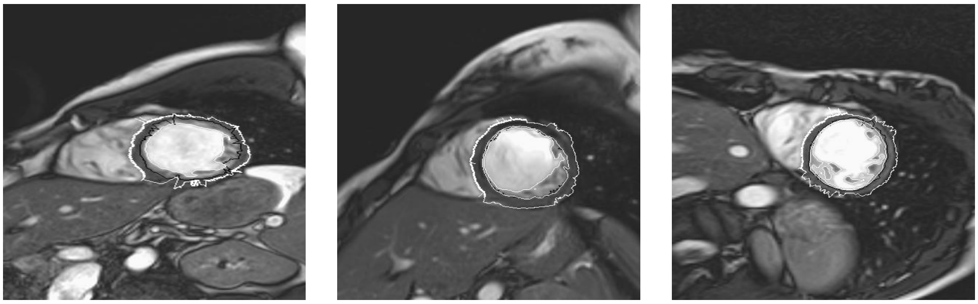


Figure 7: Outputs with LV cavity, trabecular zone and compacted zone identified for slice 4 of patients P2, P3 and P6

On the other hand, the images of the patients P12, P13 and P14 have been captured with more darkness than for the rest of the patients. Thus, the LV cavity is composed of pixels with a lower intensity and the threshold to identify the trabecular zones is lower than in the rest of the cases. Figure 8 shows the outputs of slice 8 for P12, 5 for P13 and 9 for P14. The percentage quantification of the trabecular zone is 21.50%, 23.17% and 9.55% for P12, P13 and P14. The lower intensity of the pixels is clearly observed in the three images. Therefore, it is more difficult for the cardiologists to identify and measure the different structures manually, and a significant time to process each image would be needed. The computing method also allows in these cases the faster automatical identification and measurement. The subjective evaluation by cardiologists for these identified zones is 4.5, 5.0 and 5.0, which highlighting the efficiency of QLVT in processing darkness images.

Therefore, the experiments with different types of analyzed images reveal the proposed method is capable of detecting and measuring the different zones in different situations, by adjusting the threshold to detect the trabecular zones and the intensity of the black zone to determine the external layer of the compacted zone. The time needed to obtain the final outputs

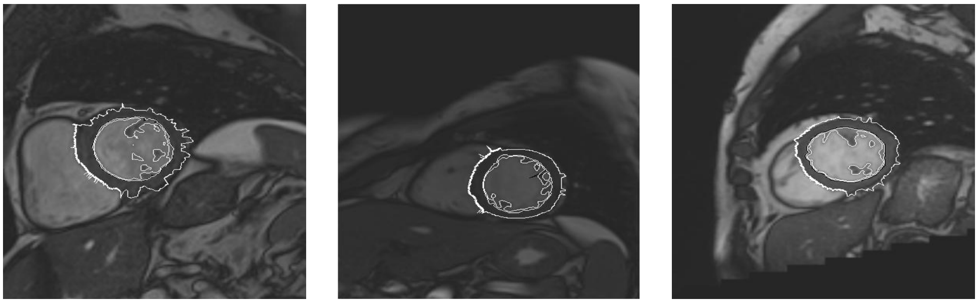


Figure 8: Outputs with LV cavity, trabecular zone and compacted zone identified of slices 8, 5 and 9 for patients P12, P13 and P14

is less than 2 minutes per image. This time is insignificant compared with the manual process traditionally used, where cardiologists need around 25 minutes per image to delimit, measure and compute the quotient of the thickness between the trabecular area and the compacted zone for all segments.

4 Conclusions and future work

We have proposed the first automatical software tool based on medical experience that accurately quantifies the LV hyper-trabeculation degree, using the cardiac images obtained by magnetic resonance.

We have presented a computing method that applies a series of computational techniques based on the ltmser algorithm [11] for the detection of stable regions implemented, in QVision [12] (a computing vision library for QT), around cardiac images obtained by magnetic resonance. QLVT automatically selects the left ventricle cavity among the different stable regions, and identifies the different stable regions inside the left ventricle myocardium. The method finds the right ventricle cavity and delimits the external layer of the left ventricle by the external layer of the myocardium and the right part of the external layer of the RV cavity. The trabecular zones are detected inside and around the left ventricle cavity. The threshold to identify the trabecular zones and the intensity of the black zone to determine the external layer of the compacted zone can be easily adjusted or configured by cardiologists. The output result is the percentage quantification of the trabecular zone with respect to the compacted area for each cardiac image of a patient.

We have applied QLVT to a wide set of patient images with non-compacted cardiomyopathy previously diagnosed due to other cardiomyopathies and people with magnetic resonance studies thanks to familiar screening who has been diagnosed as healthy, and so genetically prove negativity. Some patients received intravenous contrast before the magnetic resonance and a set of images have been captured with more darkness. The proposed method was therefore tested with several types of patients and images with different characteristics, like wide or narrow compacted zones and trabecular areas in a great range. The percentage quantification of the trabecular zone varied from 4.48 to 56.89, demonstrating that QLVT is able to detect both insignificant and very important trabecular zones. Subjective grading values obtained from the cardiologists confirm that the output images are of diagnostic quality and are medically acceptable.

The time needed to obtain the final outputs is less than 2 minutes for each image, obtaining speedups in ranges from 10 to 15 with respect to the manual process used traditionally by cardiologists.

The computing method can be extended to the exact quantification of the trabecular zones in the right ventricle. The proposed method could be used and integrated in medical centers in order to accelerate the diagnoses by cardiologists.

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References

[1] American Heart Association Writing Group on Myocardial Segmentation and Registration for Cardiac Imaging, Manuel D. Cerqueira, Neil J. Weissman, Vasken Dilsizian, Alice K. Jacobs, Sanjiv Kaul, Warren K. Laskey, Dudley J. Pennell, John A. Rumberger, Thomas Ryan, and Mario S. Verani. Standardized myocardial segmentation and nomenclature for tomographic imaging of the heart: A statement for healthcare professionals from the cardiac imaging committee of the council on clinical cardiology of the American Heart Association. *Circulation*, 105(4):539–542, 2002.

[2] Gregorio Bernabé, Jose M. García, and José González. A lossy 3D wavelet transform for high-quality compression of medical video. *Journal of Systems and Software*, 82(3):526 – 534, 2009.

[3] TK Chin, JK Perloff, RG Williams, K Jue, and R Mohrmann. Isolated noncompaction of left ventricular myocardium. A study of eight cases. *Circulation*, 82(2):507513, August 1990.

[4] R. Engberding and F. Bender. Identification of a rare congenital anomaly of the myocardium by two-dimensional echocardiography: persistence of isolated myocardial sinusoids. *American Journal of Cardiology*, 53:17331734, 1984.

[5] Joaquín Franco, Gregorio Bernabé, Juan Fernández, and Manuel Ujaldón. Parallel 3D fast wavelet transform on manycore GPUs and multicore CPUs. *Procedia Computer Science*, 1(1):1101 – 1110, 2010. {ICCS} 2010.

[6] D. Gibson, M. Spann, and S.I. Woolley. A wavelet-based region of interest encoder for the compression of angiogram video sequences. *Information Technology in Biomedicine, IEEE Transactions on*, 8(2):103–113, June 2004.

[7] A Jacquier, F Thuny, B Jop, R Giorgi, F Cohen, JY Gaubert, JM Vidal, V Bartoli, G Habib, and G Moulin. Measurement of trabeculated left ventricular mass using cardiac magnetic resonance imaging in the diagnosis of left ventricular non-compaction. *European Heart Journal*, 31:10981104, 2010.

[8] R Jenni, E Oechslin, J Schneider, C Attenhofer Jost, and P A Kaufmann. Echocardiographic and pathoanatomical characteristics of isolated left ventricular non-compaction: a step towards classification as a distinct cardiomyopathy. *Heart*, 86(6):666–671, 2001.

[9] Rolf Jenni, Norbert Goebel, Roberto Tartini, Jakob Schneider, Urs Arbenz, and Oswald Oelz. Persisting myocardial sinusoids of both ventricles as an isolated anomaly: Echocardiographic, angiographic, and pathologic anatomical findings. *CardioVascular and Interventional Radiology*, 9(3):127–131, 1986.

[10] Kenneth I. Joy. Breshenham's algorithm. In *Visualization and Graphics Research Group, Department of Computer Science, University of California, Davis*, 1999.

[11] David Nistr and Henrik Stewnius. Linear Time Maximally Stable Extremal Regions. In *Computer Vision ECCV 2008. Lecture Notes in Computer Science*, volume 5303, pages 183–196, Marseille, France, 2008.

[12] PARP Research Group. University of Murcia, Spain. *QVision: Computer Vision Library for QT*, 2012. http://qvision.sourceforge.net/.

[13] Claudia Stllberger and Josef Finsterer. Left ventricular hypertrabeculation/noncompaction. *Journal of the American Society of Echocardiography*, 17(1):91–100, 2004.